

A new biaxial apparatus integrated within a pressure vessel to test the physical properties of brittle rocks: the state-of-the-art

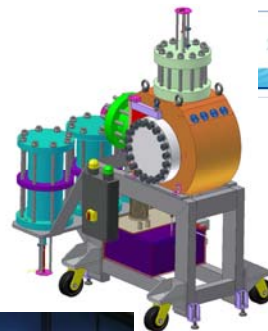
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Introduction

A main goal of the European Research Council, Starting Grant, **GLASS** (InteGrated Laboratories to investigate the mechanics of **A**seismic vs Seismic faulting), is to develop a prototype rock deformation biaxial apparatus to examine the physical properties of brittle rocks. Two layers of fault rock are sandwiched between three steel block by a normal load applied using a horizontal oil-dynamics piston. A vertical oil-dynamics piston pushes the internal rock sample of the sandwich in order to slide at constant velocity.

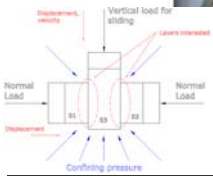
With GLASS we are going to build-up a confining pressure around the rock samples under load stress (tri-axial mode) and to measure the fluid flow properties of the rock during the deformation. Working in tri-axial mode with a fluid circulation, the machine is able to measure and to characterize frictional properties of faults on the sample for a wide spectrum of realistic conditions. We have concurrently been working to improve the control and the acquisition system for having a machine very flexible and easy to use for several applications and capable to detect different signals on the rock during frictional sliding in a fluid-rich environment with the goal of comparing these signals to those observed in nature. We began designing the servo controlled machine in October 2010 and have recently installed the apparatus in the HP-HT lab at the INGV in Rome.

First tests of this biaxial apparatus confirm the main target of the project.

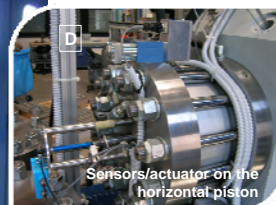


Target:

- Sample rock dimensions up to 20 x 20 cm
- Horizontal and vertical force 1.5 MN (~150 Tons)
- Confining pressure 80 MPa (tri-axial experiments)
- 8 liter available for the fluid circulating into the samples rock with pressure up to 30MPa (permeability experiments)
- Vertical sliding velocity 0.1 $\mu\text{m/s}$ - 2 cm/s
- Displacement up to 15 cm
- Vertical sliding control: displacement (velocity) feedback controlled during the experiments
- Horizontal load feedback controlled
- Manual and automatic control for a short or long experiments with different profiles: velocity steps, displacement steps, ...
- Develop of sensors for the recording the acoustic emission, seismic signals of micro-earthquakes, gas emission, ... and for studying rock properties.



Load cells and holes for sensors wiring and fluid pipe-lines



Sensors/actuator on the horizontal piston

Machine description

The machine (about 5Tons weight) consists of a stainless steel pressure vessel with internal diameter of 40 cm, equipped with 2 oil-dynamics pistons, horizontal for normal stress and vertical for shear stress. Two big steel portholes make the positioning of the holders and rock samples assembly very easy. The vessel was designed to be and maintain an internal pressure up to 850bar for the "tri-axial" mode applications. Five holes on the pressure vessel allow to connect up to 100 sensors close the sample when the portholes are closed.

One potentiometer with resolution of 0.15 μm is installed on each piston for measuring the displacement. High sensitive LVDT sensors are fixed on the horizontal and vertical pistons to validate the sliding and the deformation of the sample during the experiments. Pistons are driven by two very sensitive voltage control signals servo-valve (one is marked as D on the picture) and can work independently in load or displacement feedback control, obtaining a sliding velocity into the range 0.1 $\mu\text{m/s}$ - 2 cm between the samples.

Two load cells with a dynamic load ranging up to 150 Tons and 30Kg of sensitivity are mounted onto each vertical and horizontal pistons.

The apparatus has other three oil-dynamics pistons positioned on the kart, that operate as fluid pressure intensifier Pa, Pb and Pc and they are controlled by three proportional valves. Pa and Pb have an hydraulic gain of 1.87, Pc has hydraulic gain 4.3. The pistons intensifier Pa and Pb are dedicated for the pore fluid circulation into each sample rock, and can operate: 1) to maintain a constant pore fluid pressure into the rock sample; 2) to operate with differential pressure and induce a flow controlled across the rock coming from normal layer to shear direction.

The piston intensifier Pc is used to keep the confining pressure of oil around to the sample in a "tri-axial" mode experiments. The pipe lines of the pore fluid circulating come from a sixth hole.

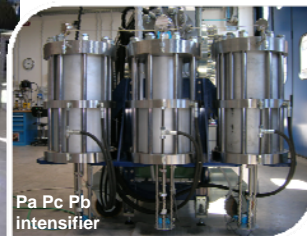


The oil-dynamics circuit

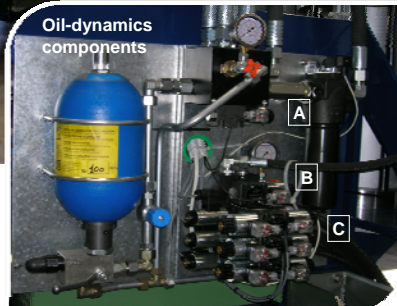
The oil-dynamics circuit is composed for many parts: a main ON/OFF valve enables the oil pressure to the vertical and horizontal hydraulic pistons. Two voltage controlled servo valve (DUPLOMATIC and MOOG), installed directly on both horizontal and vertical pistons

cylinders, modulate the oil into the piston chamber. A second ON/OFF valve (B) enables the oil pressure to the intensifiers Pa, Pb and Pc. A group of three proportional and directional DUPLOMATIC valves (C) modulate the oil flow of each piston intensifier in order to regulate the pressure of the confining oil and the flow velocity of the pore fluid.

The position limiter switches stop the movement of each pistons deactivating the main valves. The oil-dynamics plant of the machine is supplied by a group of two pumps drove by electrical engines M1 and M2. M1 is a 18 KW-4P-240-415 V/50Hz motor connected to an axial pistons pump. It provides pressure up to 220 bar to the horizontal and vertical pistons. M2 is 4 KW-4P-240-415V/50Hz motor with a second pump that provides oil pressure to the three pistons intensifier (Pa, Pb e Pc). Another motor-pump M3, located above the green tank of the oil, is used for the circulating of the oil into the cooling system. A fourth pump is used to fill the pressure vessel and this operation take about 10-15 minutes depending of the spacers.



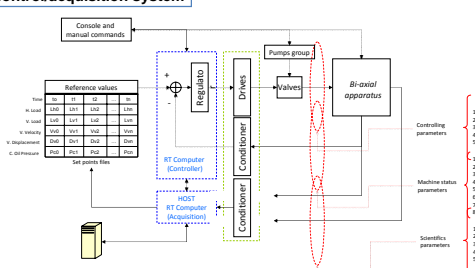
Pa Pb Pc intensifier



Oil-dynamics components

TECHICAL IMPROVEMENTS AND TOPICS TO STUDY...

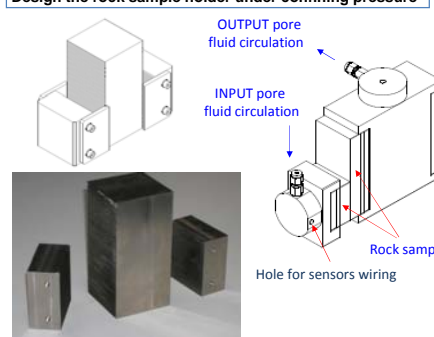
The machine control/acquisition system



Two Real Time (RT) computer operate on the machine. The machine is controlled by on board RT based PC sRIO, with a FPGA device integrated. It performs the control of the machine with high regulating speed and upgrading of the control parameters during an experiment. The controlling process (developed in LabVIEW) is very flexible and regulates the input signals of the servo-valves in order to keep the loads, the vertical piston sliding, the confining oil pressure and the pore fluid flow into the sample rock, following the reference values from a target profile, depending of the experiment. On the console the user can see the status of the machine during an experiment or gives main commands.

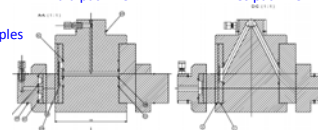
The scientific data acquisitions is operated by a second flexible PXI-PC (HOST) that read and elaborate the signals from interchangeable sensors (displacements, loads, pressure transducers and other sensors on the sample coming from different manufacturing) using high quality 24bits ADC board @100KSp. For the first testing of the machine a industrial PXI based PC was used with a generic DAQ (data acquisition) board. The software for testing was developed in LabVIEW environment implementing a synoptic user interface for rapid vision of the process.

Design the rock sample holder under confining pressure



Fluid path view

wires path view



Two 5x5 rock sample holders are now available for experiment. The first one (left side) is used for rock experiments in double direction without the fluid circulation into the rock or sensors applied. The second one is designed to work in double direction with fluid circulating into the rock sample (with drilled pipelines and external joint) to allow pore pressurisation of the fault zones and under the confining oil. Small tunnels allow to put sensors and his wiring close the sample on the side of the sample sandwich. A latex rubber jacket separates the wet rock samples by the fluid circulating and the holder from the oil confining. We are developing the new holder for 20x20cm rock samples capable to housing a matrix of sensors installed closely the rock samples that use a new and more easy jacketing system when it is used under confining oil pressure and pore fluid circulating.